

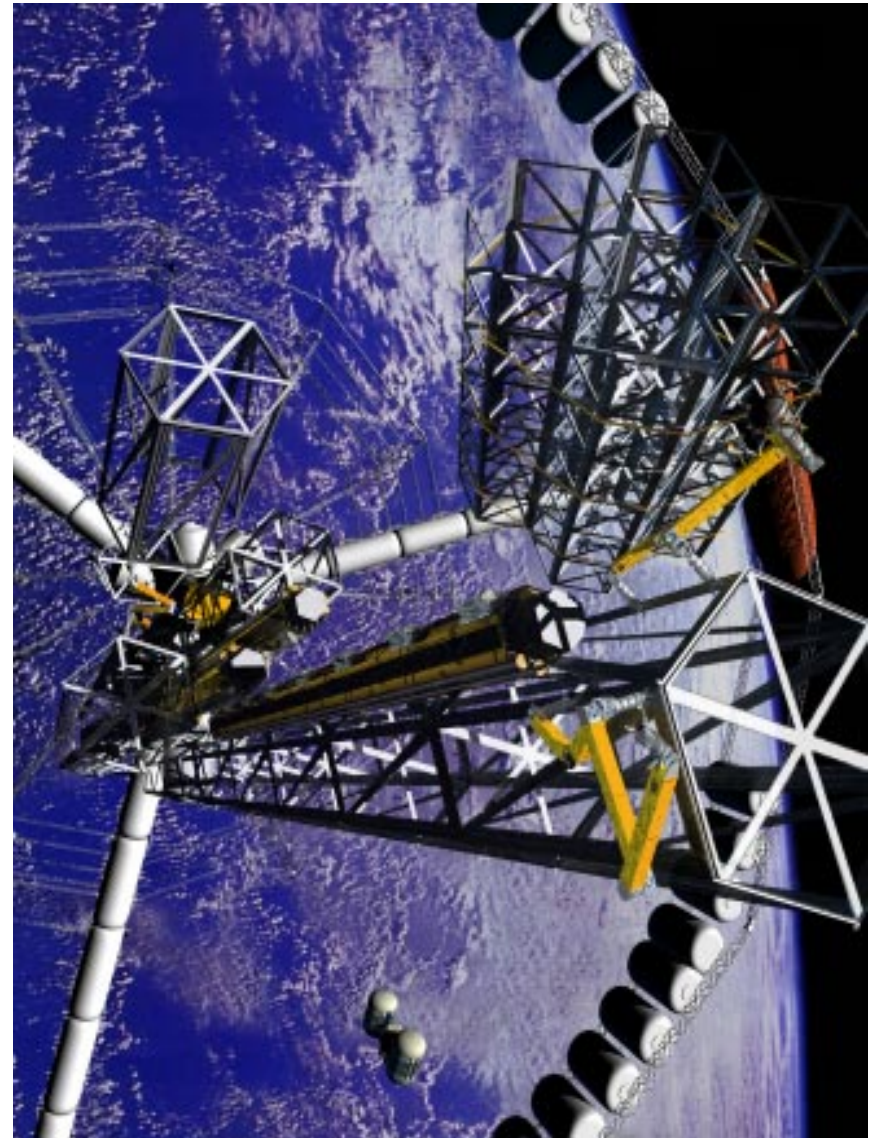
Coordination of Robotic Teams for Space Solar Power Assembly Operations

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Motivation for Robotic Operations

- ◆ Large structures
 - Millions of manipulations
 - Million kilometers traverse
- ◆ Long duration operations
 - Months of construction
 - Decades of maintenance
- ◆ Hazards
 - Temperatures
 - Kilovolts
 - Microwave Radiation
- ◆ Orbits inaccessible for humans
- ◆ Time value of assembly



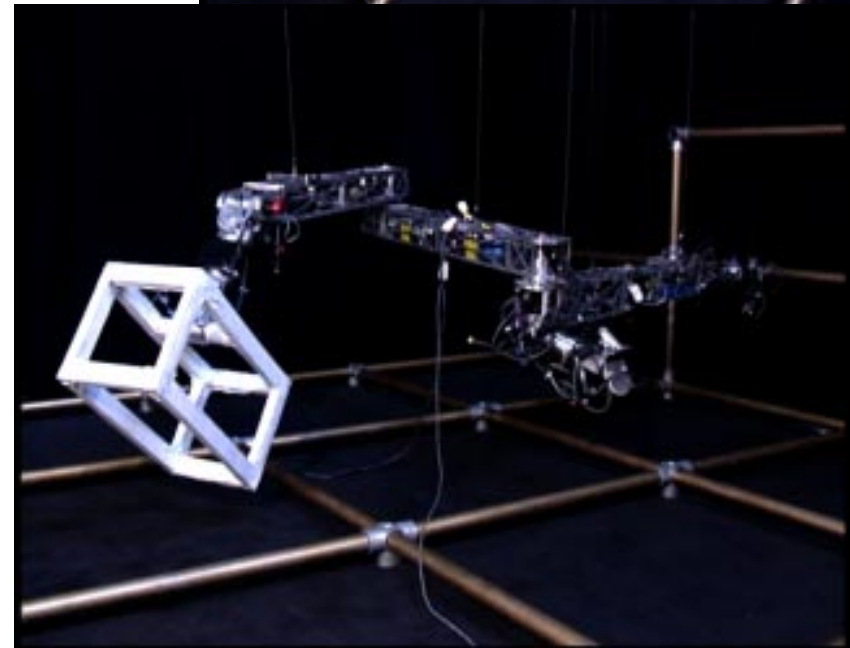
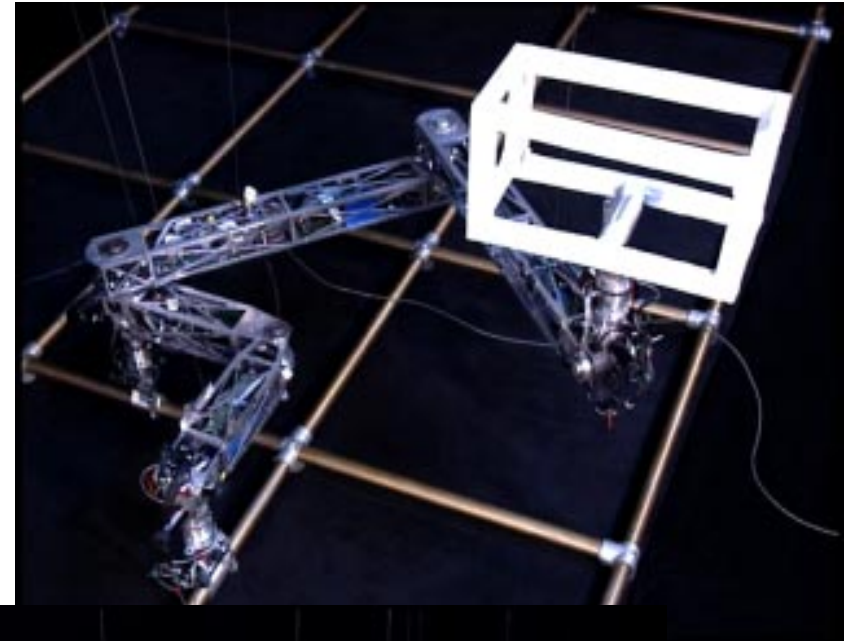
Previous Work

- ◆ Prototype Robot for Assembly, Inspection and Maintenance (AIM)
 - Developed SKYWORKER, a robot prototype for AIM tasks
 - Validated the use of structure walkers for orbital AIM
 - Developed dynamic simulation of robot, facility and tasks
 - Simulated SSP AIM relevant tasks using robotics
 - Auto-generate robot designs

- ◆ Coordinated Assembly with Heterogeneous Robots
 - Developed distributed robot architecture
 - Emphasis on tasks that cannot be done by one robot
 - Demonstrated three robot system performing docking operations

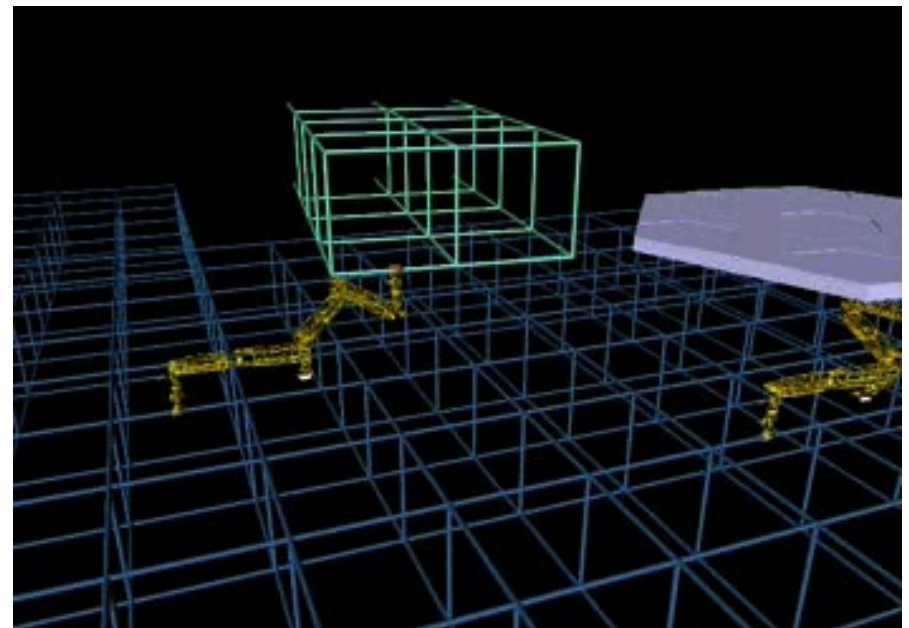
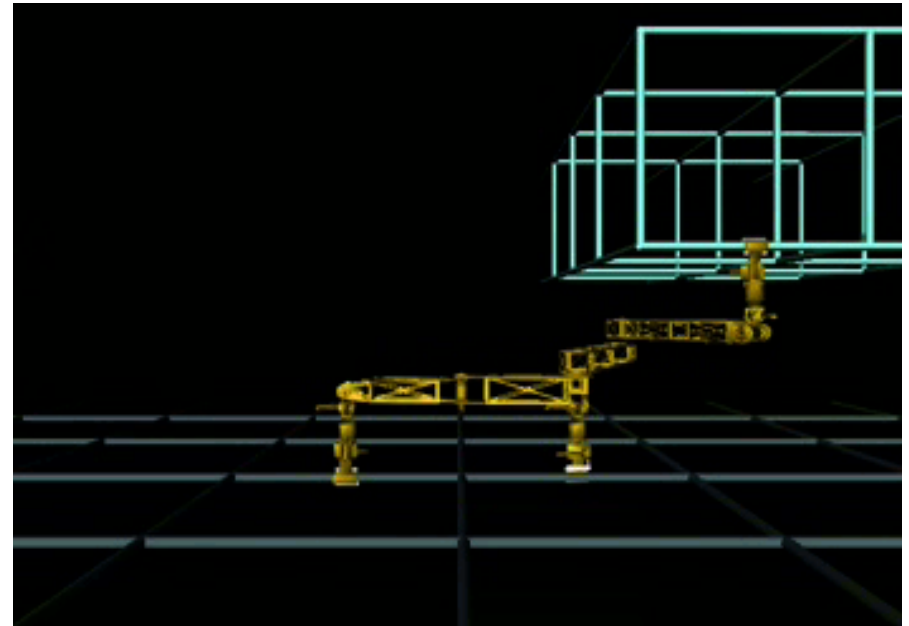
Robot Prototype: Skyworker

- ◆ Type
 - Attached Mobile Manipulator
- ◆ Task
 - Manipulation and transportation of payloads for assembly, inspection, and maintenance on space structures
- ◆ Configuration
 - Supports a continuous gait
 - Self Contained AIM prototype
 - Distributed control network



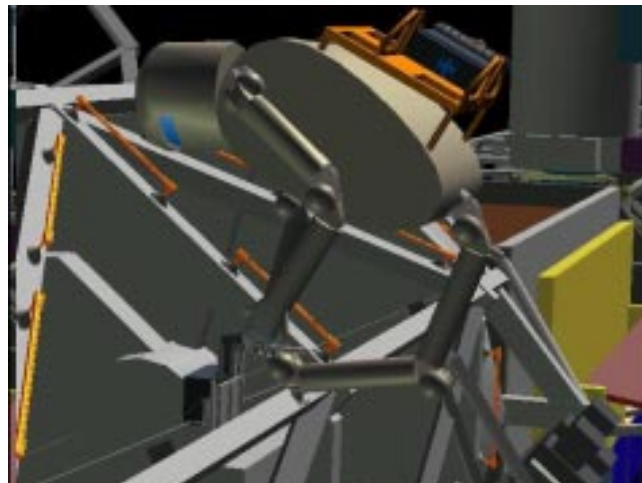
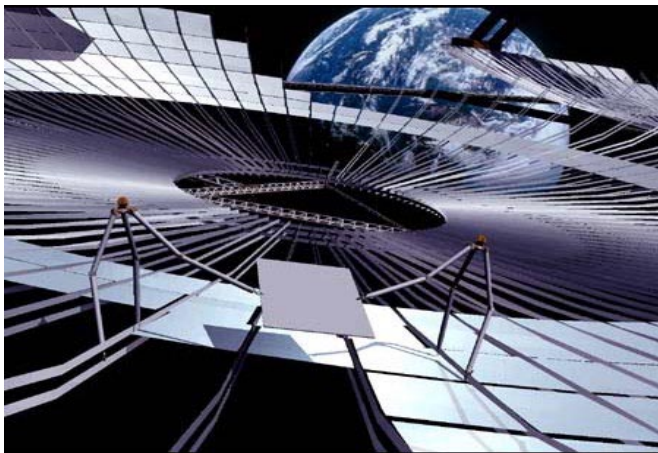
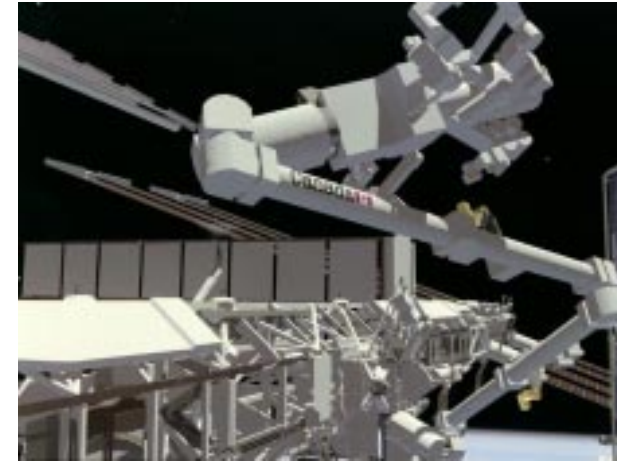
Continuous Gait

- ◆ Characteristic Gait
 - Continuous hand over hand biped gait with compensating superstructure motion allows payload to move at constant velocity
- ◆ Advantages
 - Walks Softly: Exerts minimal stress on structure
 - Consumes minimal energy



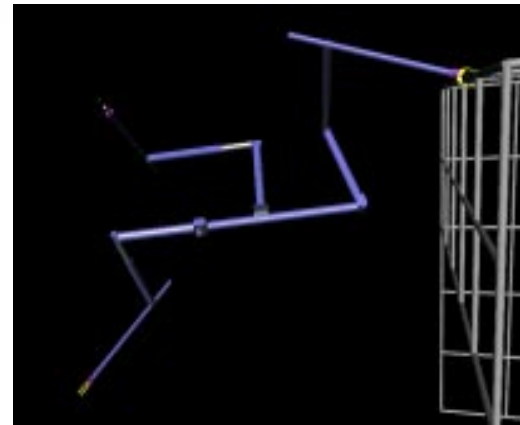
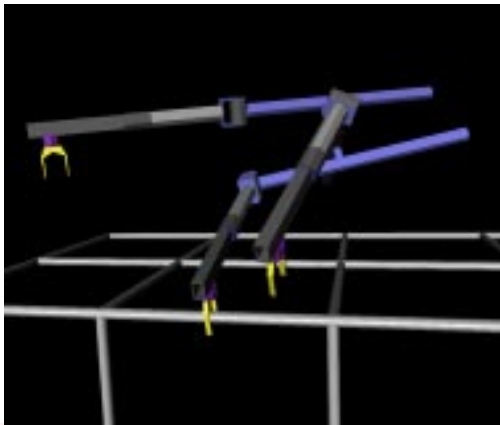
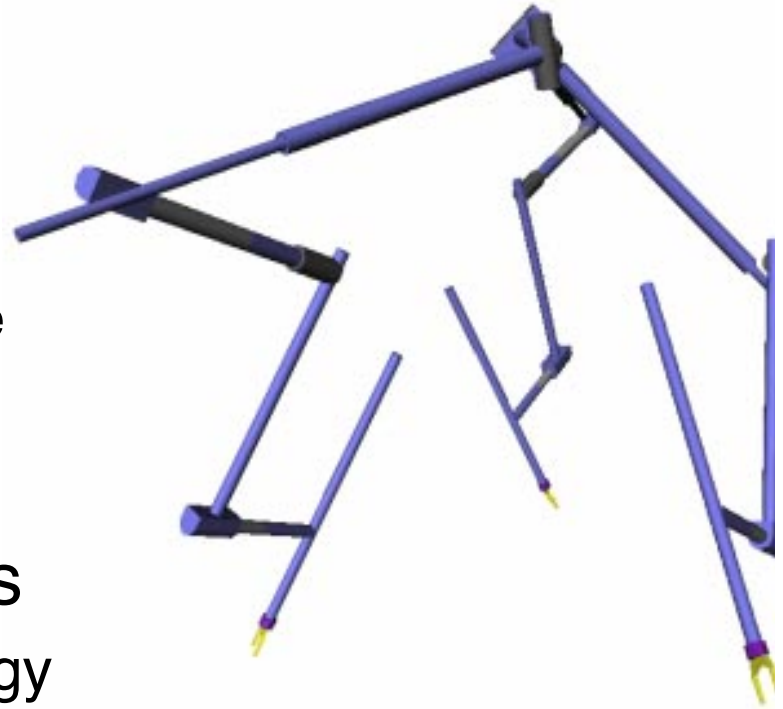
Robotic Workforce Analysis

- ◆ Model and compare robot classes
 - Free Flyers
 - Fixed Base Manipulators
 - Attached Mobile Robots (Skyworker-class)
- ◆ Model structures and elemental tasks
- ◆ Investigate viable workforce
 - Type of robots suitable for tasks
 - How many robot classes
 - How many of each class

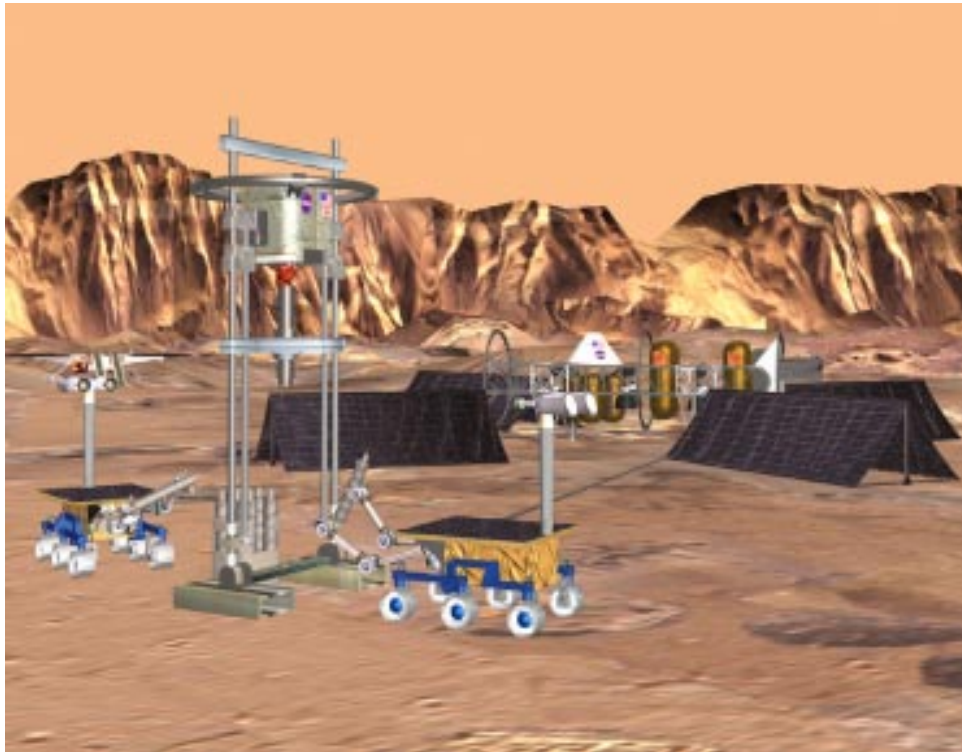


Configuration Auto - Generation

- ◆ Given a task:
 - Creates 1000's of configurations
 - Genetic algorithm optimizes:
 - Dynamic and kinematic performance
 - Control complexity
 - Power consumption
- ◆ Generated 3 AMM configurations
 - Optimize for Mass, Speed and Energy

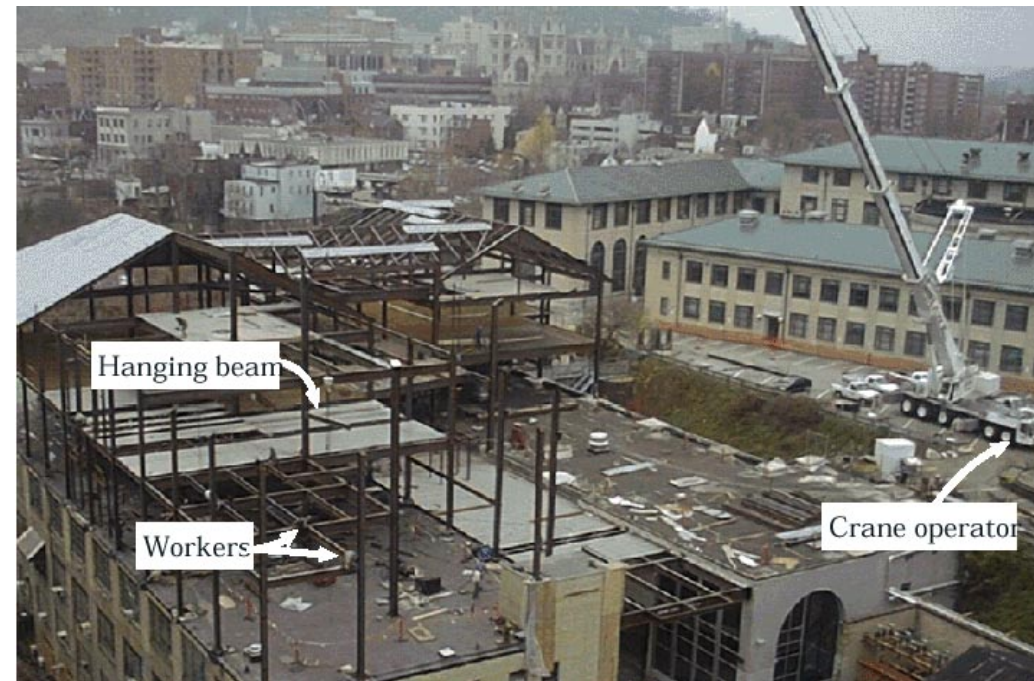


Coordinated Assembly: Motivating Scenarios

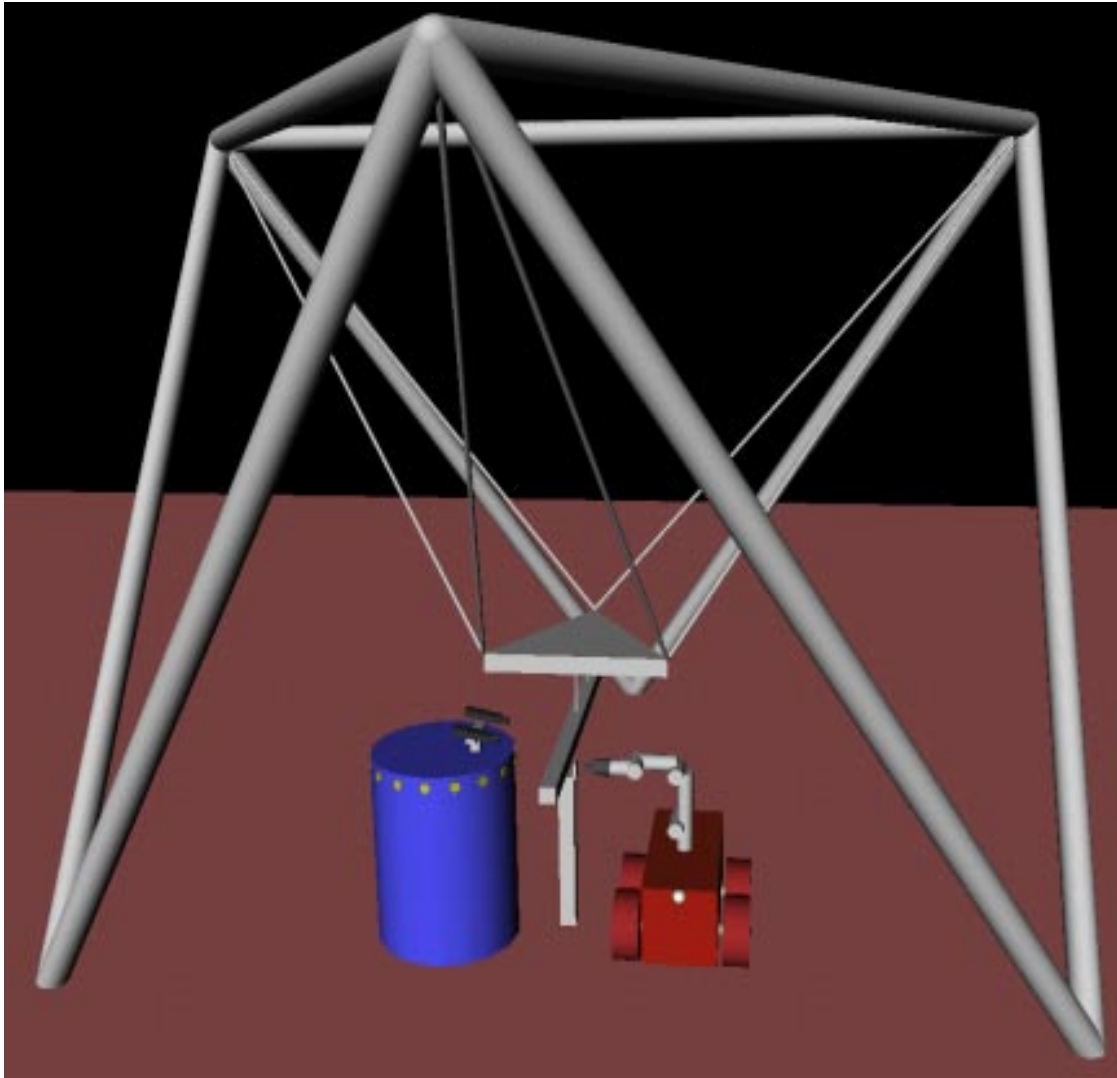


Mars Habitat Construction

Beam Enplacement and Structure Assembly

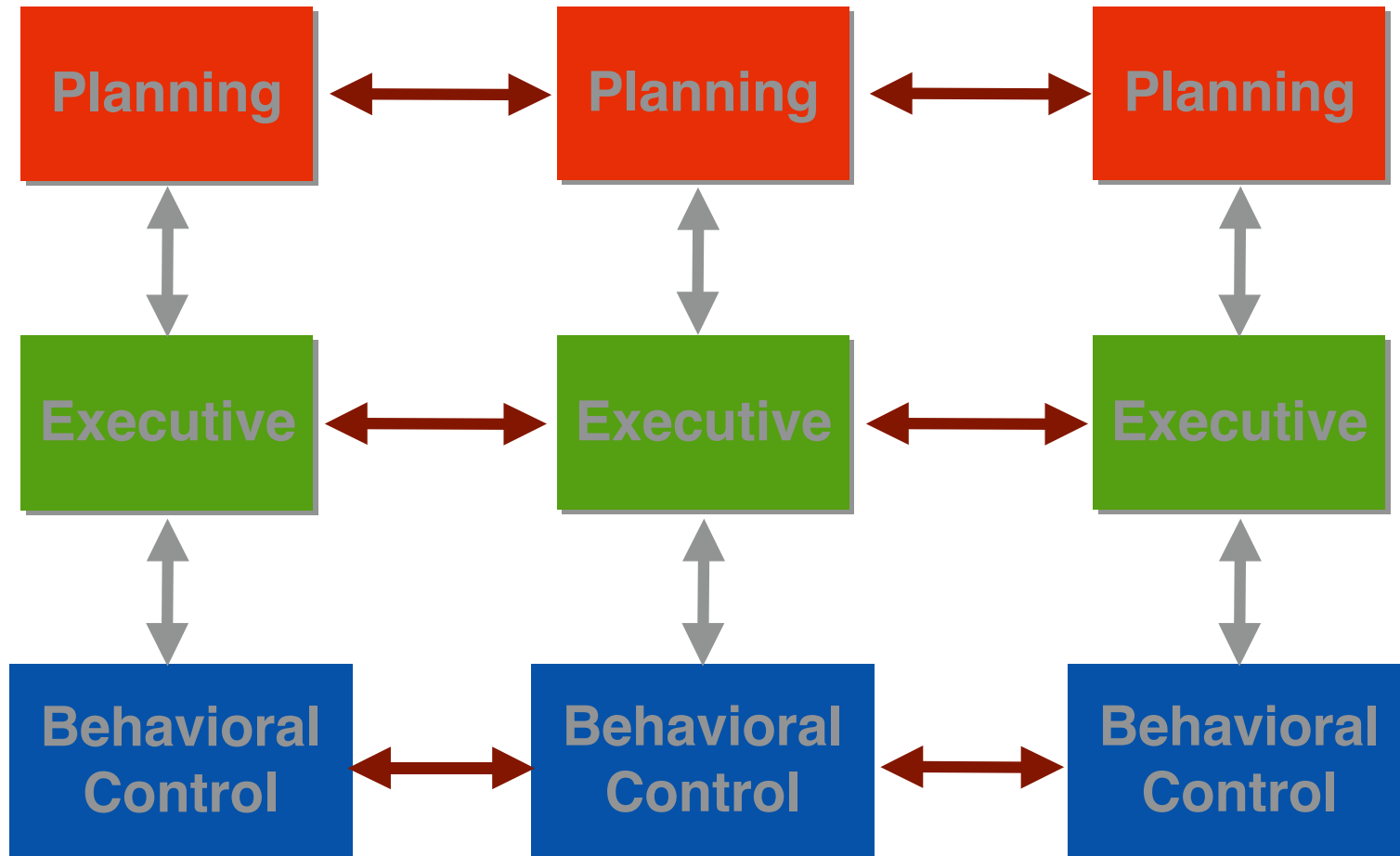


Technical Challenges: Architecture



- ◆ Coordination at campaign, control and task level
- ◆ Dynamic, distributed team formation
- ◆ Adjustable autonomy at control and task level
- ◆ Independent robot operation without accurate inter-robot calibration

Multi-Robot Tiered Architecture

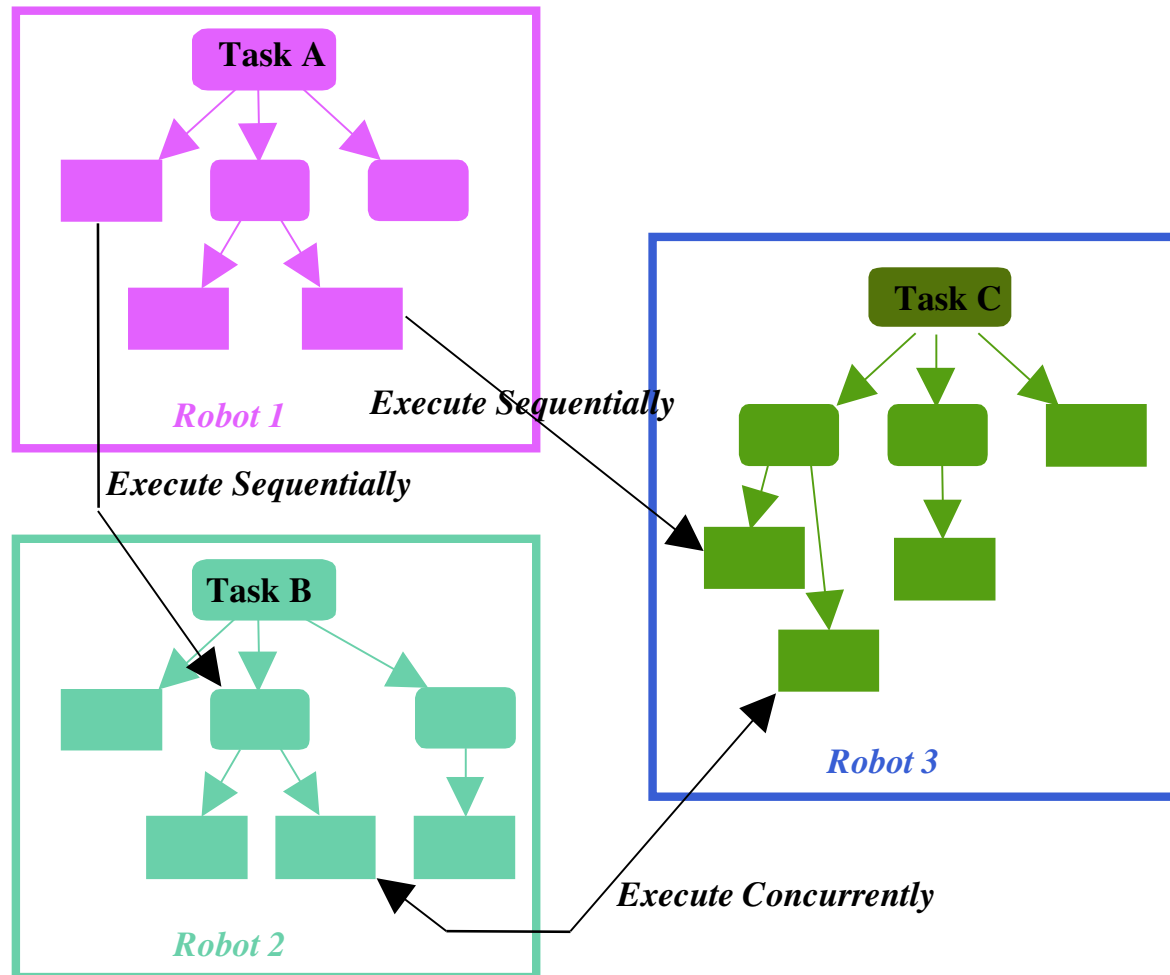


Executive Level

- ◆ Task-Level Control
 - Hierarchical task decomposition
 - Explicit task synchronization
 - Execution monitoring and exception handling
 - *Distributed execution*
- ◆ Language for Specifying Task Constraints
 - *Simple concepts* expressible in *simple terms*
 - Syntax for task decomposition, temporal constraints, monitoring, exception handling
 - Superset of C++

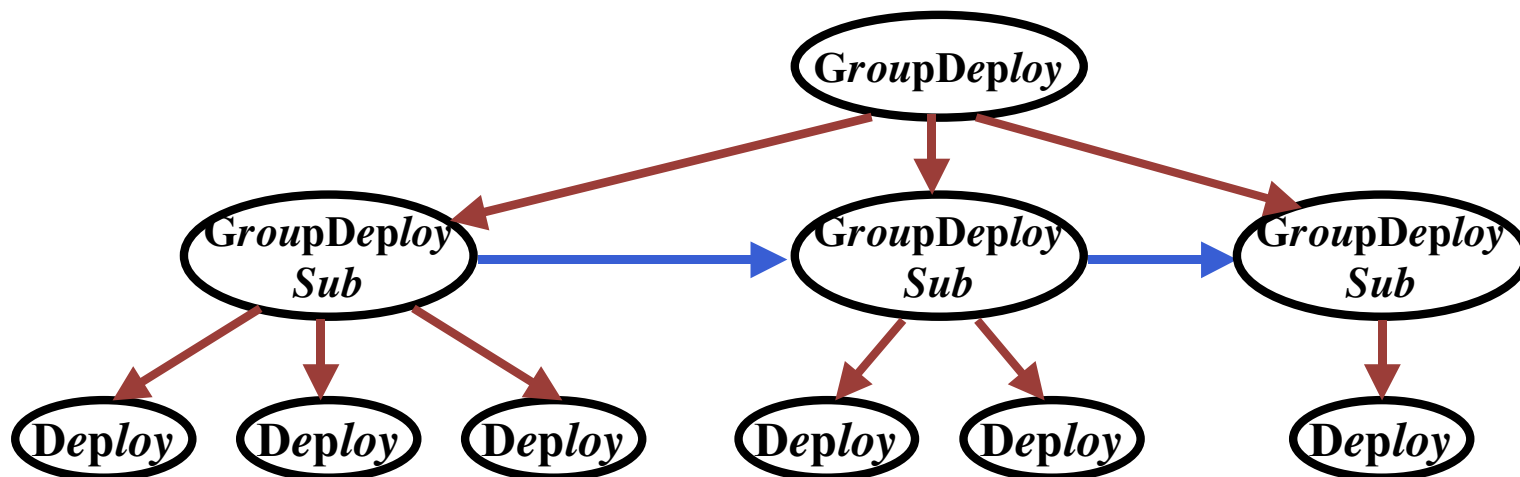
Multi-Robot Synchronization

- ◆ Enable agents to allocate and synchronize tasks; detect and handle each others exceptions

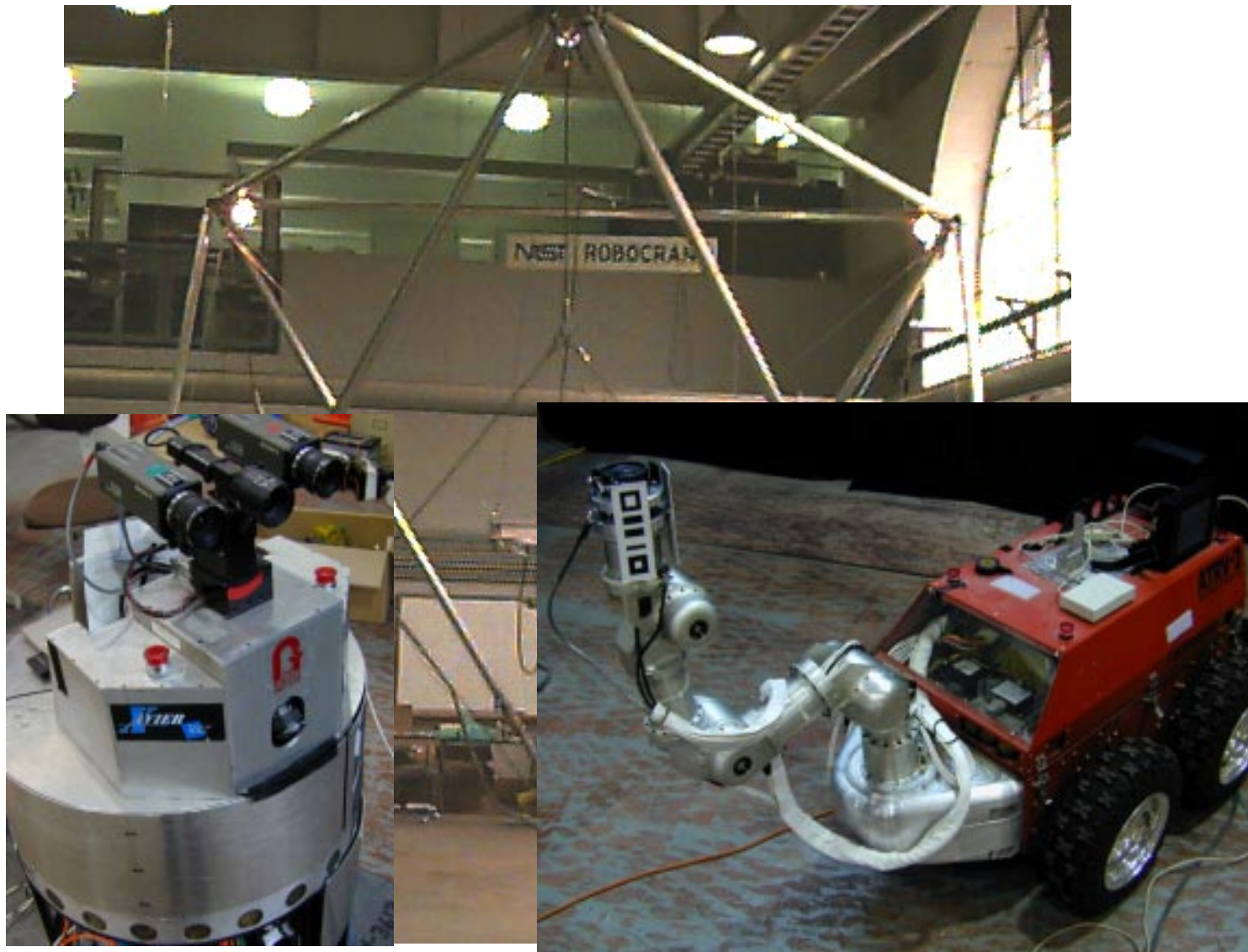


Task Trees

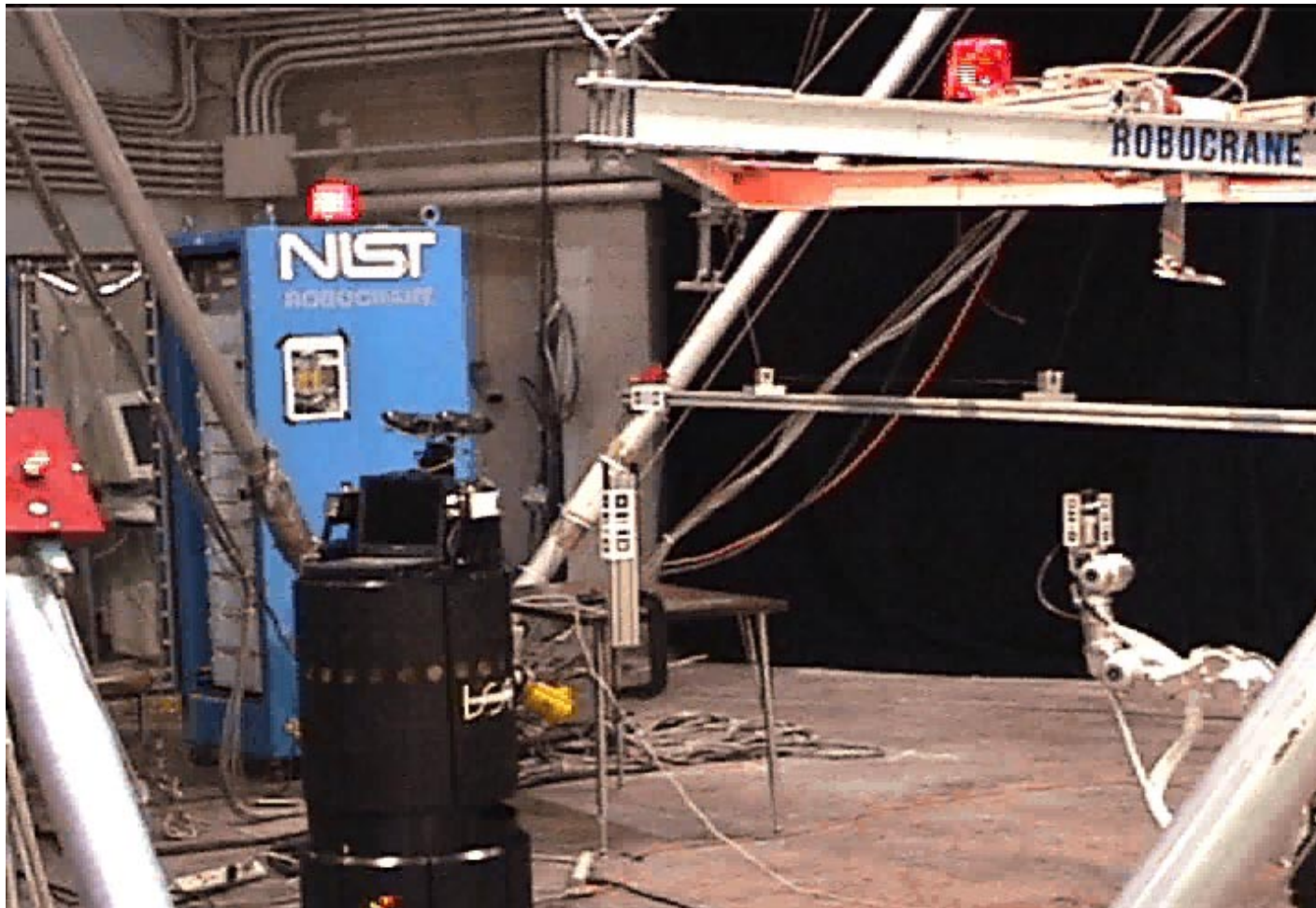
- ◆ Execution trace of hierarchical plans
 - created dynamically at run time
 - can be conditional and recursive
- ◆ Temporal constraints partially order tasks
- ◆ Hierarchical exception handlers



Multi-Robot Testbed



Coordinated Assembly



NASA/NSF project

Builds upon the two previous projects to develop
SSP relevant coordinated assembly

Objectives:

- ◆ Enable heterogeneous multiple robots to coordinate in the performance of complex assembly tasks
- ◆ Enable flexible human-robot interaction during assembly to deal with unanticipated contingencies

Motivating Scenarios:

- ◆ Assemble multi-element, compliant structure
- ◆ Brace structure for strength
- ◆ Cable structure

